Distortion Compensation Techniques for Large Reflector Antennas

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Abstract—The high-frequency limit of reflector antennas is usually governed by the magnitude of the surface error. Whereas little can be done for the high-spatial frequency portion of this error, there are various techniques that can be employed to compensate for large-scale surface errors due to gravity induced distortions for ground antennas or thermally induced distortions for spacecraft antennas. This somewhat tutorial paper describes various techniques that can be utilized to compensate for the gain-loss due to these distortions. The techniques described are 1) Main reflector compensation, 2) Subreflector compensation, 3) Use of a deformable flat plate in the optics path and 4) an Array feed compensation system. Examples are give for the use of each technique along with an estimate of the expected performance improvement.

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1. INTRODUCTION

The high-frequency performance of reflector antennas is limited by the magnitude of the surface distortions. This paper describes a number of techniques for compensating the surface errors for large reflector antennas, thus improving the high-frequency performance of the reflector antennas.

One approach to gravity compensation is to install actuators at the corners of each main reflector panel, or at the panel junctions. The actuators can either be controlled open loop if there is a-priory knowledge of the surface errors or in a closed-loop system if the surface is actively measured. This approach has been implemented on the clear aperture 100m antenna at Greenbank, West Virginia.

A second approach for gravity compensation is to install a deformable subreflector. This approach has been implemented at MIT's Haystack antenna and is one of the proposed solutions for the 25-meter ARISE antenna operating at 86 GHz.

Over the past several years' extensive work has been performed at JPL on the use of a deformable mirror to correct for the gravity induced distortions on a large reflector antenna. This work culminated in a demonstration of a deformable mirror on the NASA/JPL 70-meter antenna in early 1999. The deformable mirror, nominally a flat plate, is placed in the beam path and deformed in order to compensate for the gravity induced distortions as the antenna moves in elevation. Actuators on the mirror are driven via a look up table. Values in the look up table are derived using the distortions, ray tracing, and a structural finite element model of the mirror system. An electronic version of the deformable mirror was proposed for use with large reflector inflatable antennas for spacecraft.

An Array Feed Compensation System (AFCS) has also been studied extensively at JPL over the last decade as an alternative to the deformable mirror approach for gravity compensation. The system consists of a small array of horns, low noise amplifiers, down converters, and digital signal processing hardware and software for optimally combining the signals received by the horns.

A combined system consisting of a Deformable Flat Plate (DFP) and the AFCS was also demonstrated on the 70-meter antenna. The combined system worked better than either one of the systems acting alone.

2. MAIN REFLECTOR COMPENSATION

The Green Bank Telescope is a 100-meter, fully steerable, unblocked aperture radio telescope located in Green Bank, WV, USA. The need to operate at frequencies up to 100 GHz and low cost have led to the implementation of an instrument with an active primary reflector. Following on the heels of adaptive primary optical telescopes as well as radio telescopes that use actuators to make infrequent surface adjustments, the GBT is the first radio telescope to attempt to dynamically control a large primary.

Automated jacks supporting the primary reflector were selected as the appropriate technology (ref [1]) since they promised greater performance and potentially lower costs than a homologous or carbon fiber design, and had certain advantages over an active secondary. Since the actuators are mounted on a tipping structure, it was required that they support a significant side-load. Such devices were not readily available commercially so they had to be developed. See Figure 1 for a picture of the GBT with the actuators installed and before the addition of the main reflector panels. Additional actuator requirements include low backlash, repeatable positioning, and an operational life of at least 20 years. Similarly, no control system capable of controlling the 2209 actuators was commercially available. Again a prime requirement was reliability. Maintainability was also a very important consideration.

The system architecture is tree-like. An active surface "master-computer" controls interaction with the telescope control system, and controls ancillary equipment such as power supplies and temperature monitors. Two slave computers interface with the master-computer, and each closes approximately 1100 position loops. For simplicity, the servo is an "on/off" type, yet achieves a positioning resolution of 25 microns. Each slave computer interfaces with 4 VME I/O cards, which in turn communicate with 140 control modules. The control modules read out the positions of the actuators every 0.1 seconds and control the actuators' DC motors. Initially control of the active surface will be based on an elevation dependent structural model. Later, the model will be improved by holographic observations. Surface accuracy will be improved further by using a laser ranging system that will actively measure the surface figure.

3. SUBREFLECTOR COMPENSATION

The ARISE (Advanced Radio Interferometry between Space and Earth) will be a space based mission consisting of a 25 m radio telescope looking at the outer reaches of the universe. The RF wave front errors from the 25m deployable primary reflector can be eliminated by shape compensating the secondary reflector via mechanical adjusters.

Composite Optics, Incorporated (COI) fabricated a 1m graphite demonstration model reflector (Figure 2) that illustrates the deformable or 'adaptive' membrane concept proposed in the ARISE secondary reflector concept. The reflector is relatively lightweight and has a surface accuracy that is typical for 83 GHz antenna systems. Using mechanical adjusters attached to the membrane reflector skin deformations on the order of +/- 2mm can be achieved. The reflector surface is mapped after local deformations are imposed via the adjusters and compared to Finite Element Model predictions.

The basic elements of the demonstration reflector are a support structure, actuators, and a face skin. The support structure was designed to conform to the face skin, meaning

the distance from the face skin to the support structure at any point was constant. This allowed for the actuators to act normal to the face skin. A holding fixture was added to simulate an attachment interface and for handling purposes (see Figure 1).

COI, under NSF SBIR funding has developed and demonstrated a code for defining the adjustments necessary for bringing any given surface to the lowest possible RMS, given a measurement of the surface errors. Accurate surfaces can be achieved using the adaptive membrane design. With 36 actuators attached to the membrane a surface RMS of 1.4 mils (.035 mm) was measured after the reflector assembly was completed. Distortions in the reflector membrane can readily be achieved in a predictable manner using actuators pushing and pulling across the membrane. The magnitude of distortions of 3 mm above and 1 mm below the nominal surface were demonstrated using actuators. The analysis accurately predicts the surface deformations both in magnitude and shape. This is important in that the analytical model must be capable of predicting deformations due to adjuster loading. Secondly, the adjustment process modifies the reflector surface in a smooth transitional manner over the localized area.

4. DEFORMABLE FLAT PLATE AND ARRAY FEED COMPENSATION SYSTEM

A deformable mirror near the focus of a millimeter wave radio telescope has been discussed in Ref [3]. In that study, the mirror consisted of a number of discontinuous square segments that were activated by pistons. Each segment was several wavelengths long. Results of an JPL investigation on the use of a deformable flat plate (DFP) to compensate for the gravity-induced surface deformations of a 34-meter diameter main reflector at Ka band frequencies was presented in Ref [4]. The DFP (Figure 3) employed in that study was a smooth continuous surface, realized by 16 electromechanical actuators attached to a thin aluminum surface. It was demonstrated that the DFP was able to completely compensate for the gain-loss due to the surface-distortion in the main reflector.

During the period from November 1998 through February 1999, a series of measurements was carried out on the 70-m antenna at DSS 14 to determine the performance characteristics of two systems designed to compensate for the effects of elevation-dependent gravity distortion of the main reflector on antenna gain. The array feed compensation system (AFCS) and the deformable Flat plate (DFP) system both were mounted on the same feed cone, and each was used independently as well as jointly to measure and improve the antenna aperture efficiency as a function of elevation angle. The experimental data are presented in [5] and [6] and the theoretical formulation in [7].

The basic experimental geometry consisted of a dual-shaped 70-m antenna system, a refocusing ellipse, a DFP, and an

array feed system (see Figure 4 for the ellipse/DFP geometry and Figure 5 for the AFCS). To provide physical insight into the systems performance, a focal plane field plot is provided for 85° elevation. It shows that for large distortions, energy spills past the AFCS. Curves of predicted verses measured performance is shown for the DFP system, AFCS, and combined DFP/AFCS system in Figures 7–9. The results show that the combined

Figure 1. GBT actuators before panel installation

Figure 2. Arise COI Demo Subreflector (back side)
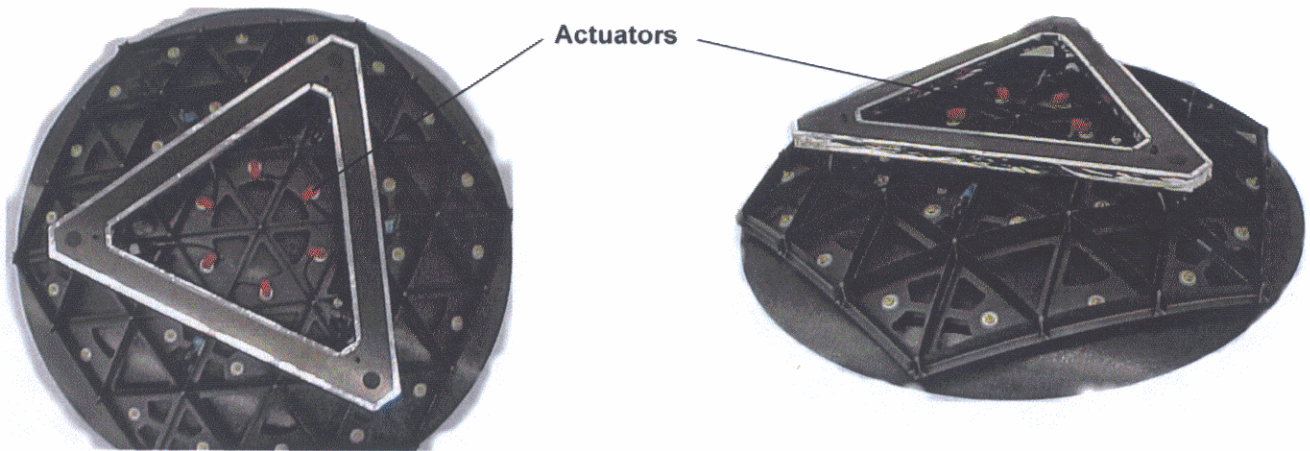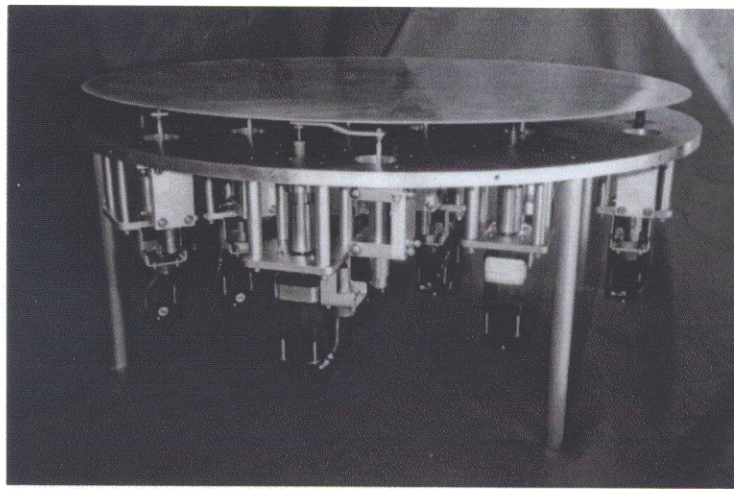
Actuators

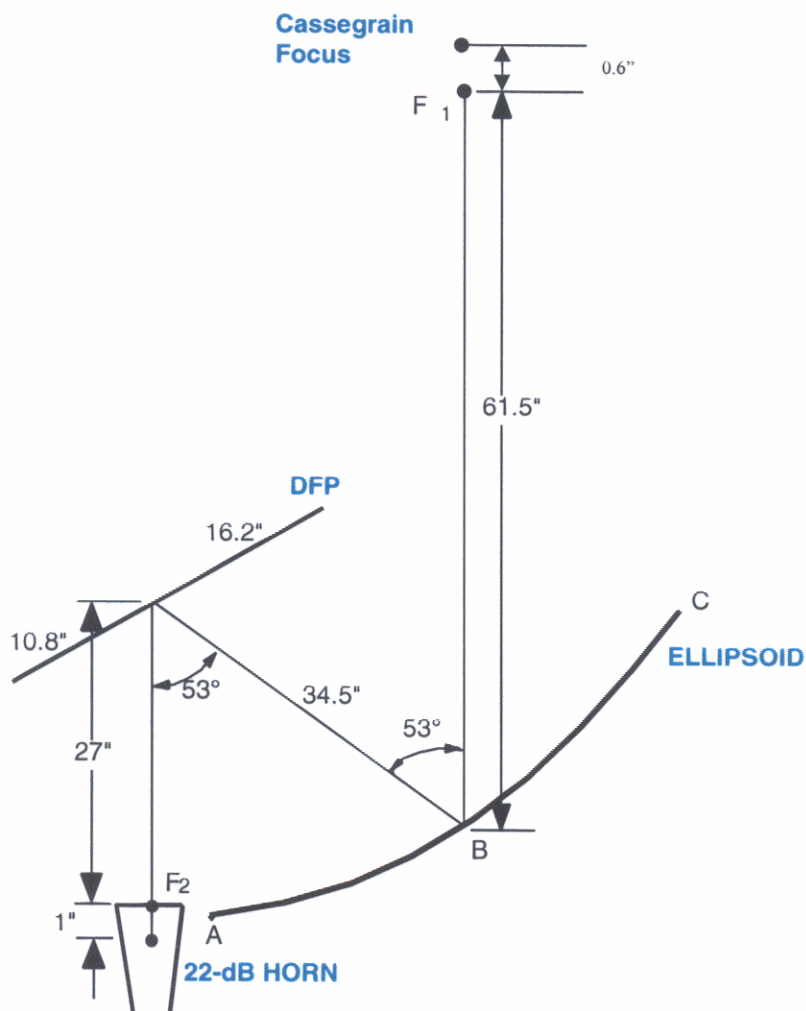Figure 3. 16 actuator Deformable Flat Plate (DFP)

Figure 4. The RF optics design inside the holography cone, showing the geometry that enables both separate AFCS and DFP measurements at F1 and F2, respectively, and joint AFCS-DFP measurements at F2. The antenna Cassegrain focus was 0.6 in. (1.5 cm) above F1, which was corrected for alignment of the subreflector in the z-axis.
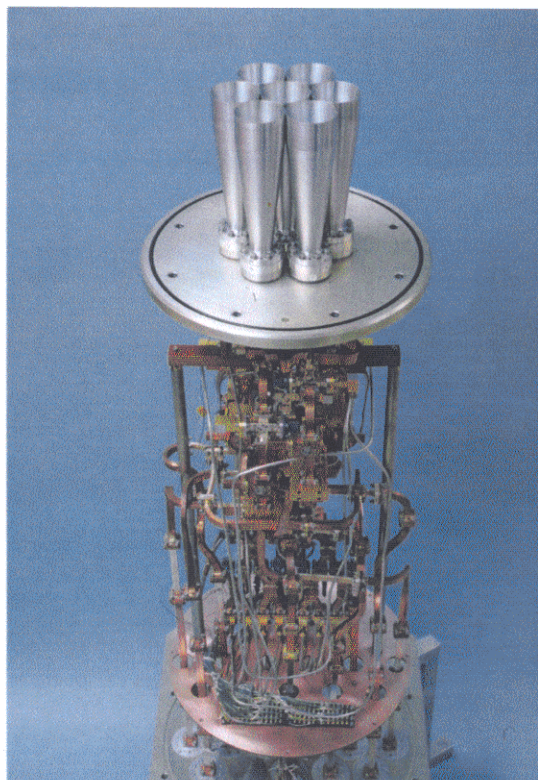
Figure 5. 7 element Array Feed Compensation System (AFCS)
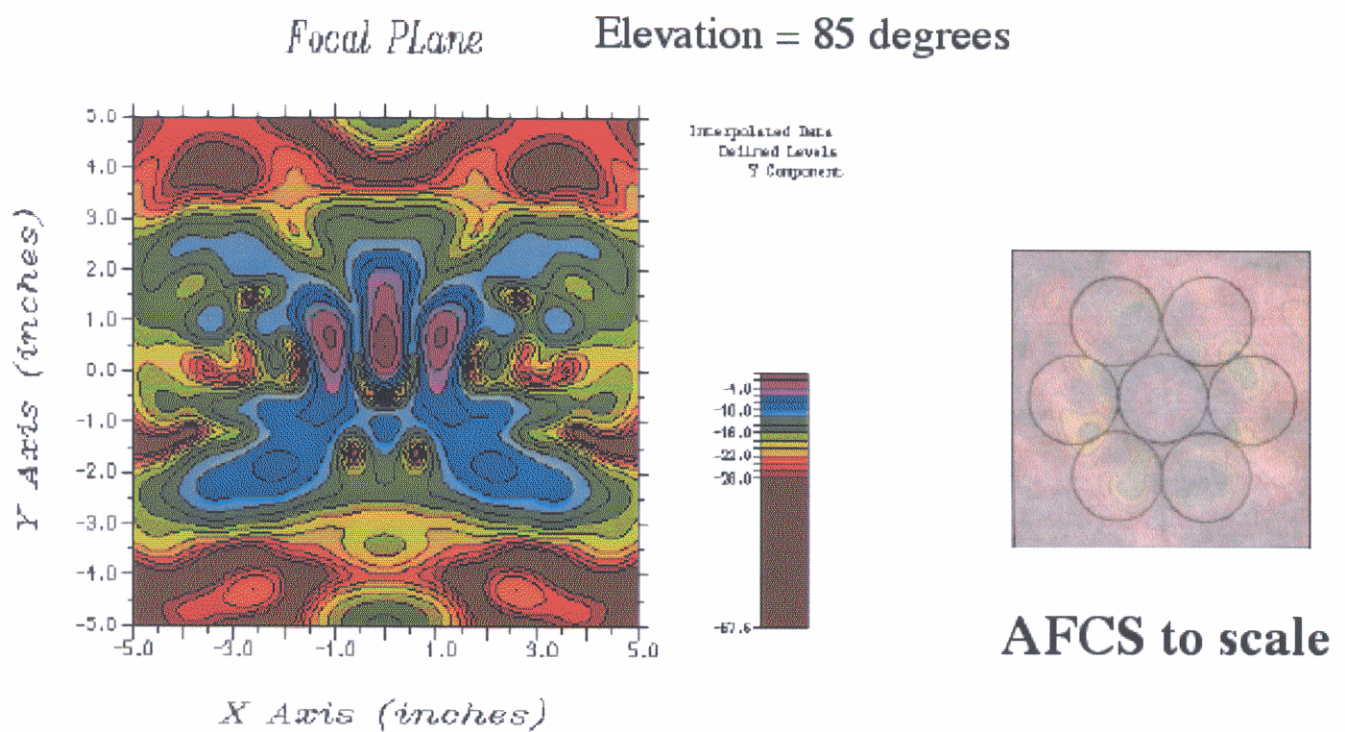

Focal Plane Elevation = 85 degrees

Figure 6 Focal Plane distribution of dual reflector system
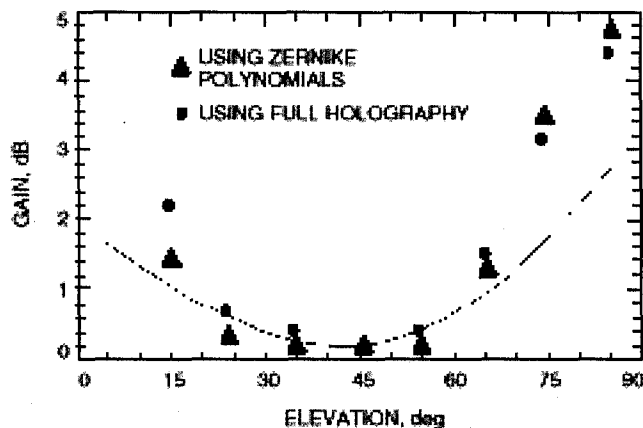Elevation = 85 degrees

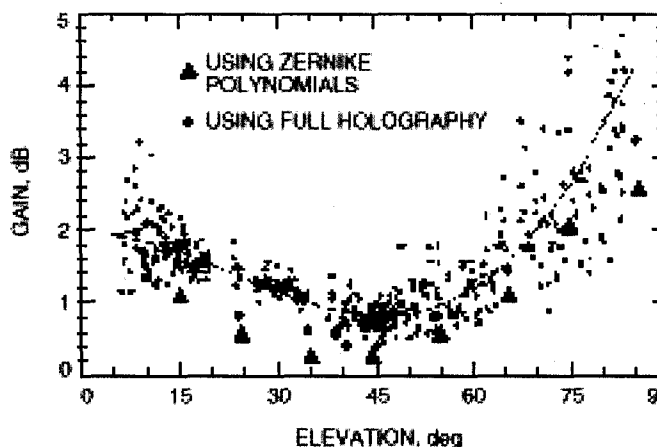Figure 7. Predicted and Measured Improvement for the DFP

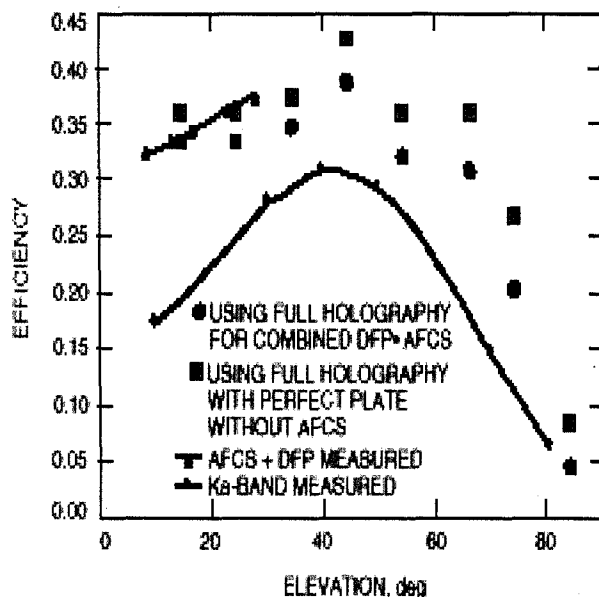Figure 8. Predicted and Measured Improvement of the AFCS

Figure 9. Predicted and measured compensation with the combined DFP-AFCS (70-m antenna efficiency at Ka-band)

DFP/AFCS system is capable of recovering the significant amount of the gain lost due to gravity distortion.

5. CONCLUSIONS

Main reflector compensation provides the best overall performance and can completely compensate for the loss due to smooth varying distortions. Subreflector compensation is second best, but can also do an excellent job if the distortions are not too large. When neither of the above solutions are possible, using a DFP in the optics path can provide substantial improvement. If it is not possible to modify the reflector geometry, then an array feed can be used to partially compensate for the distortions.

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http://tmo.jpl.nasa.gov/tmo/progress report/42-140/140I.pdf

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Dr. Imbriale is a Senior Research Scientist in the Communications Ground System Section of the Jet Propulsion Laboratory in Pasadena, California. He is leading the activities for several advanced technology developments for large ground station antennas as well as supporting advanced technology in lightweight spacecraft antennas and submillimeter wave instruments. Previously, Dr. Imbriale was the Assistant Manager for Microwaves in the Ground Antennas and Facilities Engineering Section, and was responsible for all the technical activities associated with the RF design and development of the Large Ground-Based antennas of the DSN. In 1991, he was on a six-month temporary assignment as a Foreign Research Fellow at the Institute of Space and Astronautical Science in Japan working on mesh deployable spacecraft antennas and beamwaveguide ground antennas.

During the 1980's he was Manager of the Radio Frequency and Microwave Subsystem Section, responsible for the research, development and implementation of the RF and microwave subsystems used in the DSN. He was manager during the critical period of equipment delivery for DSN support to the voyager mission, which included upgrades to virtually all telecommunications subsystems.

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